COMPOSITIONS AND AGES OF APOLLO 15 LUNAR IMPACT AND VOLCANIC GLASSES: FIRST RESULTS

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Introduction: The ages and compositions of lunar impact glasses, droplets of melt formed in energetic impact events on the Moon, have been used to address questions related to the impact history in the Earth-Moon system [1, 2, 3, 4, 5], to address how those impacts may have affected life on Earth [6], and to investigate the regional geology of the collection site [7]. Here we present the first results of compositional studies of impact glasses from the Apollo 15 landing site, as well as compositional information about the well-studied Apollo 15 volcanic glasses. The major- and trace-element compositions of the impact glasses can be used to probe the crustal composition in the area around the Apollo 15 landing site, while the volcanic glasses can provide information about episodes of local mare volcanism.

The Apollo 15 Landing Site: The Apollo 15 landing site is on the easten margin of the Imbrium Basin and was selected so that the Apennine Front and the eastern rim of Hadley Rille could be examined. The Apennine Front was most likely formed by ejecta from the Imbrium impact, while Hadley Rille was probably formed by volcanic processes.

Compositional variations among and within the many Apollo 15 samples has been ascribed to mixing of mare and highland materials [e.g., 8, 13]. Regolith from the Hadley Rille area is similar in composition to the mare basalts but richer in incompatible trace elements [8], while regoliths from the Apennine Front area are characterized as feldspathic soils with variable contamination by mare basalt [8, 9].

Numerous studies of the Apollo 15 volcanic green glasses have revealed discrete compositional groups, with Mg-numbers ranging from 60.4 to 67.0 [10, 11, 12, 13]. Explanations for this variation include mixing between magma and olivine [13] and mixing between two contemporaneous, but chemically distinct, magmas [10]. A recent study [14] using KREEP basalts collected at the Apollo 15 site is investigating the range in magma compositions represented by these samples.

Sample Analyses: 115 glasses from Apollo 15 regolith 15221,21 were separated into size fractions of 75 – 150 μm and >150 μm, mounted individually in Crystalbond, hand-polished, and analysed for major and trace elements. Major elements were measured by EMP (Cameca SX 100) or by EDS-SEM (Jeol 6400), while trace element concentrations and Pb isotope data were collected by laser ablation ICPMS (Agilent 7700). Sample preparation and these analyses were conducted at The Australian National University. Operating conditions for the EMP included a 15-keV electron beam, a specimen current of 20 nAmps, and count times between 10 and 30 sec for each element, with backgrounds collected for every element. Operating conditions for the SEM included a 15-keV beam, a 1-nA speciment current, a scanning area of 10 μm × 10 μm, and two-minute analyses on each major element. Operating conditions for the ICPMS are as described in [19]. Terrestrial USGS glass standards and lunar working standards were analyzed during each session.

Impact glasses were distinguished from volcanic (i.e., "pristine", "picritic") glasses according to their CaO/TiO_2, MgO/Al_2O_3 and CaO/Al_2O_3 compositions [after 15, 16 and references therein; Fig. 1]. Impact glasses came in a variety of shapes (e.g., spherule, dumbbell, shard) and colors (e.g., red, yellow, orange, green, brown), while volcanic glasses were limited in shape (e.g., shard, spherule) and color (e.g., red/brown, green). Based on major element analyses, 28% (32/115) of the glasses were of impact origin.

Discussion: Regolith sample 15221,21 was collected at Station 2, on the Apennine Bench and should be dominated by impact glasses possessing a highlands component. However, only 16.5% (19/115) of the glasses have this composition (Fig. 1). The average K_2O (wt%) is ~0.03%; some of the glasses closely resemble the KREEP-poor impact melts [e.g., 18]. At least a few of the glasses are similar in composition to the yellow impact glasses identified by [17]. Impact glasses that fall outside of the "typical" Apollo 15 regolith composition have been identified and may reflect large and distant (i.e., "exotic") impact events; studies to determine this are ongoing. $^{40}Ar/^{39}Ar$ ages for a subset of these glasses will be determined.

The vast majority of the glasses (72%; 83/115) have been identified as pristine, volcanic, glasses. In general, the Apollo 15 mare glasses possess the VLT composition of the Apollo 15 volcanic green glasses, though a smaller number of particles have a low-Ti composition [18]. Several glasses fall outside of the general linear trend that represents local regolith but lie near to the compositions of established volcanic glasses [12; Fig. 2]. They may therefore reflect a more diverse volcanic composition than has been seen before.

Trace-element compositions have been obtained for 65 glasses and will be used to further distinguish among chemical groups of glasses. In general, the impact glasses are lower in alkalies compared to refractory Ba, which supports the low-K measurements in these glasses.

Chemical ages of the Apollo 15 impact glasses derived from U-Th-Pb concentrations [19, 20] are mostly ≤500 Ma, though one KREEP-rich particle has a chemical age of ~3.9 Ga. These ages will be compared to the $^{40}Ar/^{39}Ar$ ages when they become available.

Conclusion: Impact glasses from 15221,21 reflect the diverse compositions found in the Apollo 15 regoliths. This range reflects the variation in the regolith compositions, which may be due to binary mixing between the volcanic mare material at Hadley Rille and the highland material at the Apennine Front. Why this sample is overwhelmingly dominated by volcanic glasses is an interesting question.

Young ages (≤500 Ma), as inferred from the U-Th-Pb concentrations, are abundant in the impact glasses [20], reflecting small impact events near the Apollo 15 landing site. Data from these glasses, together with impact glass data from other lunar landing sites, will help us to investigate the geochemical evolution of the lunar surface and to better estimate the impact flux in the Earth-Moon system.

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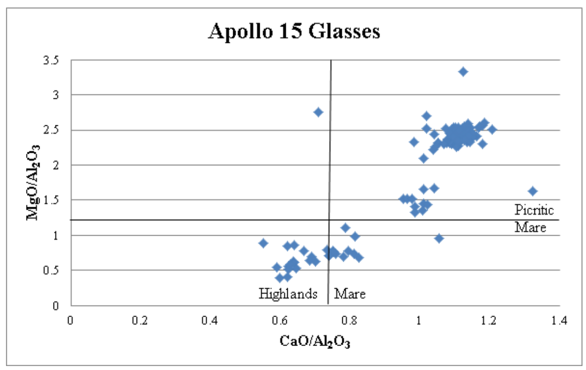

Figure 1. Plot showing 15221,21 glasses with highlands or mare compositions, as well as of impact or volcanic origin, after [16] and references therein.

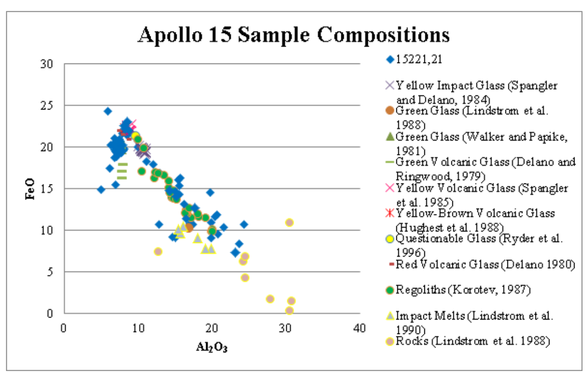

Figure 2. Comparison plot of FeO *vs.* Al_2O_3 showing the range of compositions of the lunar glasses from 15221,21 compared to published compositional data of other Apollo 15 glasses, regoliths, and rocks.